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AIR LIME AND NATURAL HYDRAULIC LIME MORTARS WITH CERAMIC RESIDUES FOR REHABILITATION OF OLD BUILDINGS

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Abstract *Repair of old facades renders requires particular attention because raw materials currently available hardly ever correspond to the requirements for this purpose. Usually, in those cases, air lime mortars are more suitable; however, they imply long curing periods. Alternative solutions such as natural hydraulic lime mortars might reveal appropriate. In the past, it was also common the use of ceramic fragments and dust in mortars for plastering and rendering, which improved their behaviour. Considering the high amounts of residues currently produced by ceramic industries, the development of mortars with this residue might be a technically viable solution, and also respond to economic and environmental issues.*

In the present paper it is described a part of a large experimental campaign involving the characterization of air lime and natural hydraulic lime mortars with ceramic residues from bricks, roof tiles and pottery. A comparison is made between the results obtained for the two groups of mortars, considering physical and mechanical properties. Volumetric proportions of 1:2 (air lime mortars) and 1:4 (natural hydraulic lime mortars) were used and ceramic residues replaced 20%, 30% and 40% of the aggregate (common sand).

The obtained results show that the incorporation of ceramics might provide significant changes in mortars porous structures and, consequently, in their mechanical and physical behaviour. Globally, when considering the studied properties, the analysed mortars may be regarded as suitable for rehabilitation purposes.

1. INTRODUCTION

In ancient times, in the absence of natural pozzolans, ceramic milled residues were frequently used as artificial pozzolans and also as aggregates (fine and coarser particles), providing some hydraulicity and durability to air lime mortars. In Portugal it is possible to find construction ruins from the Roman Empire period with several examples of the incorporation of these materials in mortars and plasters. Troia and Conimbriga archaeological sites are two of the most known cases.

Figure 1. Troia archaeological site (Portugal).

Ceramic dust was frequently used in plasters or pavements coatings and coarser ceramic fragments were used for the production of masonry mortars, especially in structural elements such as arches and foundations, and also in buildings elements with waterproofing requirements (baths, aqueducts and tanks) [1,2].

In the rehabilitation context, it is important to recognize old mortar´s solutions and to develop similar products. Therefore, lime mortars with ceramic residues may become a viable answer for the maintenance of old facade renders. When considering environmental issues associated with the building industry, it is fundamental do develop sustainable products that give priority to waste recovery. Portuguese ceramic industries produce, according to the European Pollutant Release and Transfer Register, about 102 329 tons of solid non-hazardous waste per year [3].

Several authors have been analysing mortars with ceramic residues, most cement based [4,9], achieving promising results. However, lime based mortars for rehabilitation purposes have been barely studied. This paper shows several results obtained for air lime and natural hydraulic lime mortars with ceramic residues milled from bricks, tiles and pottery from Portuguese industries, which are a part of a major investigation developed in ITeCons, University of Coimbra and Nova University of Lisbon. Volumetric proportions of 1:2 for air lime mortars and 1:4 for natural hydraulic lime mortars were used and the aggregate (a common river sand) was partially replaced by the milled residues. Properties such as mechanical strengths, water vapour permeability and water absorption at 28 days for air lime mortars and 60 days for natural hydraulic lime mortars are analysed.

2. EXPERIMENTAL CAMPAIGN

2.1. Materials

The studied mortars were prepared with hydrated powder air lime, CL90, provided by Lusical, and natural hydraulic lime, NHL 3.5, provided by Secil, as binder (EN 459-1) [10], a common river sand and ceramic residues as aggregates. The common siliceous river sand and also the ceramic waste that were used as aggregate were characterized in what concerns to their particle size distribution, fineness modulus [11], water absorption [12], loose bulk density and percentage of voids [13]. Ceramic wastes from bricks, roof tiles and ceramic pottery were gathered in Central Region of Portugal industries and were grinded in a laboratory Retsch jaw mill, with a 10 mm cribble. Properties of the aggregates are presented in previous documents [14, 15, 16]. All aggregates were classified as medium sized. In what concerns to loose bulk density, wastes presented lower values than river sand and both were much higher than natural hydraulic lime and air lime. Also, wastes presented higher water absorption after 24 hours of immersion (from 8% to 14%) than river sand (near 0%), which must be considered when analysing the results obtained from all mortars.

2.2. Mortar characterization

Air lime mortars, designated as 2A, were prepared with a volumetric proportion of 1:2 (binder:aggregate) and natural hydraulic lime mortars, 4H, with 1:4. In the first group (air lime), river sand was replaced by 20% and 40% of each type of ceramic residue. For hydraulic lime mortars, sand was replaced by 30% of each ceramic residue. All mortars with 20% of residue were designated as L (low), mortars with 30% as M (medium) and 40% residue mortars as H (high). Mortars with brick residue were named B, with roof tile T and mortars with pottery were designated as P. Reference mortars, R, without residues, were also studied, in order to evaluate the influence of each type and amount of waste in mortars behaviour. It was set a range of flow table consistency in fresh state, determined according to EN 1015-3 [17], from 135 to 165 mm, and therefore, the water added during mixing accomplished this condition.

Mortars were mixed according to EN 1015-11 [18]. For flexural and compressive strength prisms with 40x40x160 (mm) were prepared; they were also used for water absorption by capillary test and porosity. Cylinders with 100 mm diameter and 17 mm high were used for water vapour permeability test. Tests were performed after 28 and 60 days and specimens were kept at 20ºC and 95% relative humidity (RH) in the first 5 days of curing, remained 2 more days at 20ºC and 65% RH and were then demoulded. The last conditions were maintained until test. Whenever possible, the results obtained after curing were compared with recommended values for mortars with rehabilitation purposes [19].

Table 1 presents the volumetric proportions of mortars’ components, consistency in fresh conditions and also water/binder ratio. It was observed that mortars with higher percentage of brick waste required more water to achieve the desired consistency. Also, for similar water/binder ratio, mortars with high percentage of tile waste and with low percentage of pottery waste presented lower consistencies. Air lime mortars’ water/binder ratio (by weight) was higher than hydraulic lime mortars, as they required more water to achieve similar consistencies. Natural hydraulic lime mortars with brick waste presented also higher water/binder ratio, when compared to the other NHL mortars. In fact, this occurrence might be related to the water absorption of this type of waste [15].

Table 1. Mortars composition, water binder ratio and consistency

Mortar	Air lime (CL90)	Natural Hydraulic Lime (NHL3.5)	Volumetric Proportion					Water /binder (-)	Consistency (mm)
			B	T	P	Sand	lime: ceramic:sand		
2AR	1	-	-	-	-	2	1:2	1.66	164.8
2ALB	1	-	0.4	-	-	1.6	1:0.4:1.6	1.66	152.4
2AHB	1	-	0.8	-	-	1.2	1:0.8:1.2	1.87	164.3
2ALT	1	-	-	0.4	-	1.6	1:0.4:1.6	1.66	163.1
2AHT	1	-	-	0.8	-	1.2	1:0.8:1.2	1.66	148.2
2ALP	1	-	-	-	0.4	1.6	1:0.4:1.6	1.66	149.2
2AHP	1		-	-	0.8	1.2	1:0.8:1.2	1.51	156.1
24HR	-	1	-	-	-	4	1:4	1.23	159.6
4HMB	-	1	1.2	-	-	2.8	1:1.2:2.8	1.44	173.2
4HMT	-	1	-	1.2	-	2.8	1:1.2:2.8	1.34	160.9
4HMP	-	1	-	-	1.2	2.8	1:1.2:2.8	1.37	165.8

2.2.1. Mechanical strength

Flexural and compressive strength tests were performed according to EN 1015-11 [18] and three prismatic specimens were used for each mortar and curing period. Compressive strength was determined with one of the halves resulting from flexural strength test and the other half was used to assess water absorption due to capillary action. Figure 1 presents flexural strength results, St_F, and Figure 2 compressive strength, St_C. Standard deviation obtained for each sample is also presented as well as the minimum values recommended for mortars for rehabilitation purposes: *R_inf* corresponds to rendering and plastering mortars and *J_inf* to repointing mortars.

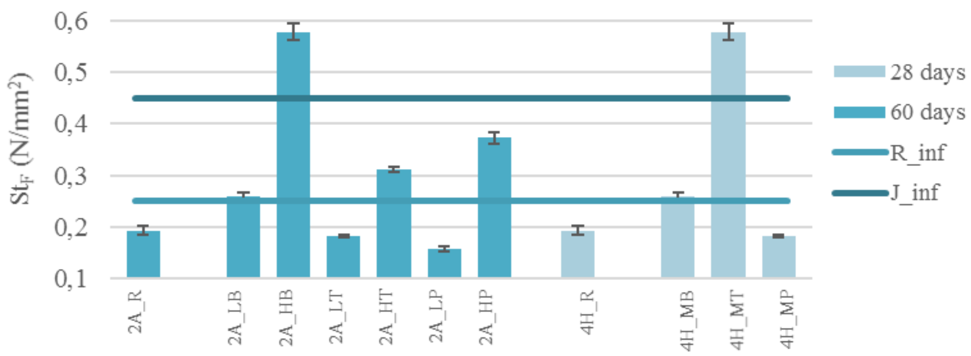

Figure 1. Flexural strength of air lime mortars (60 days) and hydraulic lime mortars (28 days).

For air lime mortars, it was observed that the increase of the amount of residues had a direct impact in flexural and compressive strength. Mortars with 40% of ceramic waste obtained much higher strengths than mortars with 20%, which were close do reference ones. Natural hydraulic lime mortar with ceramic roof tiles waste presented higher flexural strength than other NHL mortars; however, this diference was not registered for compressive strength. When comparing CL and NHL groups, generaly CL mortars presented lower strength, except for 40% brick waste mortar. It must be considered, however, that CL mortars have slower curing processes, as carbonation leads to higher strengths after longer curing periods (that can be beyond a year). It can also be seen that some of the mortars with residues present values higher then the minimum ones recommended for mortars for rehabilitation purposes.

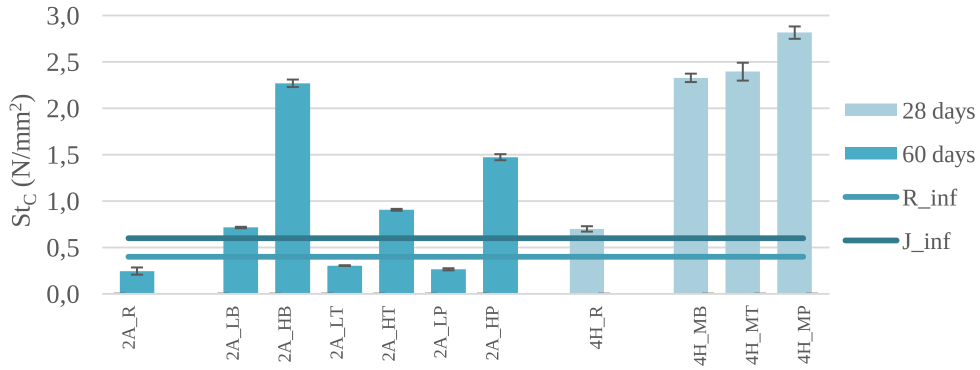

Figure 2. Compressive strength of air lime mortars (60 days) and hydraulic lime mortars (28 days).

2.2.2. *Water absorption due to capillary action*

Guidelines from EN 15801 [20] were followed to determine water absorption due to capillary action, as this standard is more appropriate for porous slow curing mortars as air lime ones. Measurements were performed at 5, 10, 15, 30, 60, 90, 120, 180 min and each 24 h after first contact of the specimens with water, until constant mass was reached. One of the remaining halves from flexural strength test was used. The first hour's absorption curve is shown in Figure 3. Water absorption coefficient of each mortar is represented in Figure 4, as well as its standard deviation. Also, the range of recommended values for rehabilitation purposes is represented with *CC_inf* and *CC_sup*.

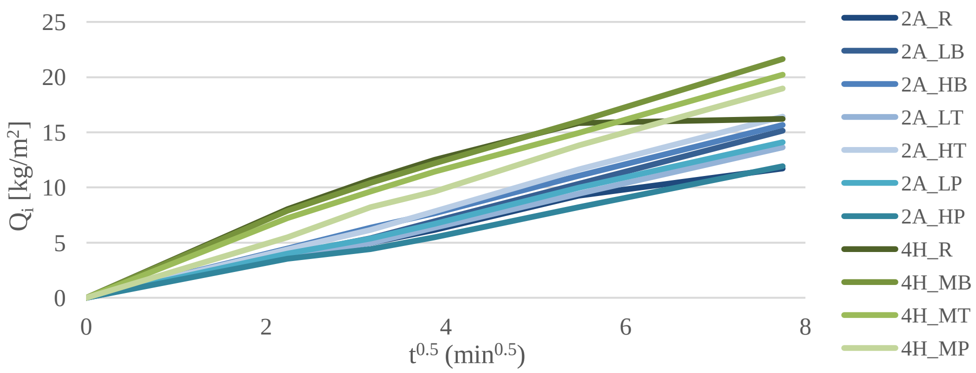

Figure 3. Water absorbed in the first hour of air lime mortars (60 days) and hydraulic lime mortars (28 days).

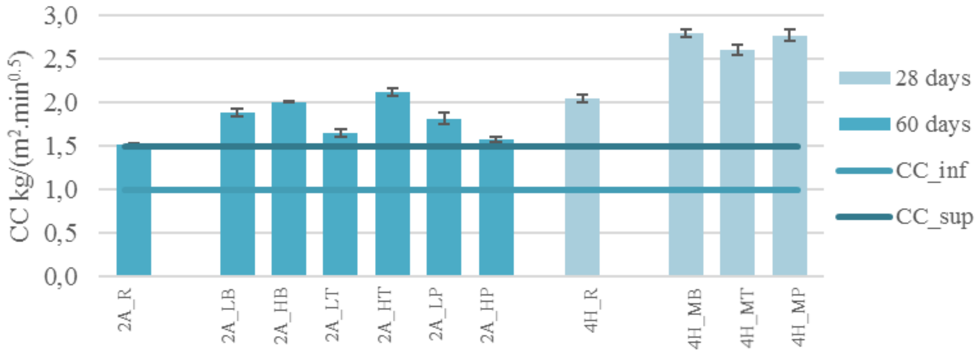

Figure 4. Capillary coefficient of air lime mortars (60 days) and hydraulic lime mortars (28 days).

It was observed that when residues are added the capillary coefficient increases and that increase is in aggrement with the amount of residues, except for air lime mortar with pottery residues. When comparing CL and NHL groups, generaly CL mortars presented lower values for capillary coefficient. In the case of water absorption due to capilary action it can be seen that all the mortars with residues present values higher then those recommended for rehabilitation purposes.

2.2.3. Open porosity

Open porosity of mortars, ρ_O, was estimated considering the procedure described in EN 1936 [21], for natural stone products. Simple immersion until complete saturation of the specimens was used, and vacuum conditions were discarded, to avoid specimens damaging. The relation between total open pores and specimens' volume was estimated. Results are presented in Figure 5, as well as their standard deviation.

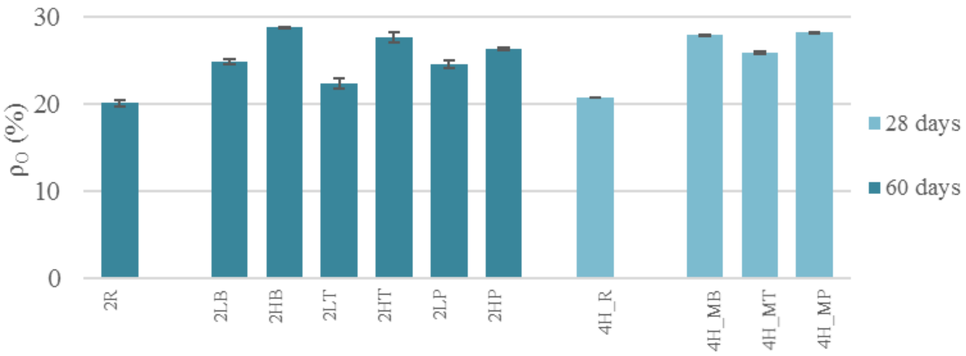

Figure 3. Open porosity of air lime mortars (60 days) and hydraulic lime mortars (28 days).

In what concerns to open porosity it was observed that the increase of the amount of residues had a direct impact in it. Higher amount of residues leads to an increase on open porosity. When comparing CL and NHL groups, generaly the obtained values are very similar.

2.2.4. Water vapour permeability

Water vapour permeability test was performed considering EN ISO 12572 [22] procedure and wet cup method was followed. Water vapour permeability, water vapour resistance factor and water vapour diffusion-equivalent air layer thickness, S_D, were determined. The results of the equivalent air layer thickness are presented in Figure 6, as well as standard deviation obtained for each mortar. Upper limits for S_D recommended values for rendering and plastering mortars, *R_Sup*, and to repointing mortars, *J_sup*, are also represented in the chart.

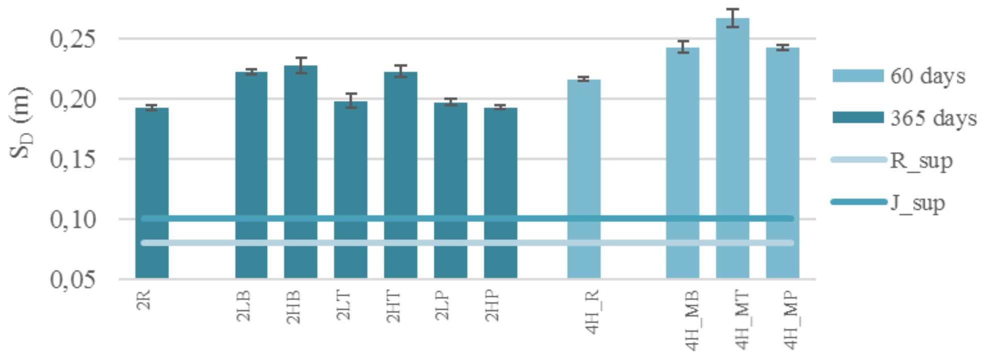

Figure 4. Water vapour diffusion-equivalent air layer thickness of air lime mortars (60 days) and hydraulic lime mortars (28 days).

With regard to water vapour permeability it was observed that the addition of residues has same influnce on it. As the amonut of residues increases, the water vapour permeabitiy decreases a little execpt to air lime mortar with pottery residues. When comparing CL and NHL groups, generaly CL mortars present lower values for water vapour permeability. In the case of water vapour diffusion-equivalent air layer thickness it can be seen that all the mortars with residues present values higher than those recommended for rehabilitation purposes.

3. CONCLUSIONS

The main conclusions to be drawn from this study are:

- Waste generated and disposed in landfill is, increasingly, a serious environmental problem that needs to be addressed; therefore the study of possible uses of wastes as building materials is a major challenge. If, in addition to this advantage, the improvement of the properties of these building materials can be achieved, a double benefit is obtained.

- In what concerns to mortars' mechanical behaviour in hardened conditons, and when analysing indicative values for replacement mortars applied as plasters, flexural strength of the mortars must be above 0.2 N/mm^2 and under 0.7 N/mm^2 and compressive strenght must be within 0.4 N/mm^2 and 2.5 N/mm^2. It can be observed that air lime mortars with higher amount of residues and all of the natural hidraulic lime mortars fullfil these requirements.

- For water absorption due to capillary action and water vapour permeability and when analysing indicative values for replacement mortars applied as plasters, capillary coefficient of mortars must not be higher than 1.5 kg/(m^2.min$^{0.5}$) and water vapour diffusion-equivalent air layer thickness must not be higher than 0.10 m. It can be seen that all the mortars with residues have higher values.

- Although the studied mortars do not meet all the requirements to be used as mortars for rehabilitation new studies are being developed to improve their behavior due to the presence of water, namely with the introduction of water-repellent additives in order to obtain the required values.

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